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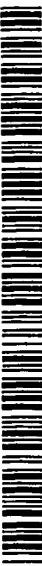
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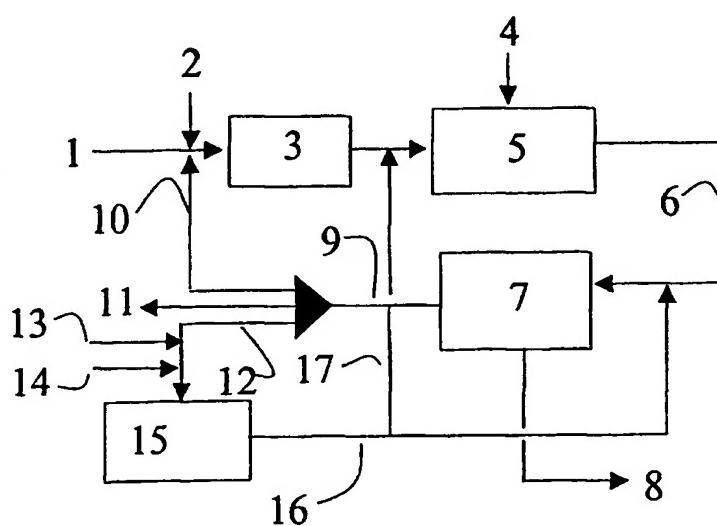
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(54) Title: OPTIMUM INTEGRATION OF FISCHER-TROPSCH SYNTHESIS AND SYNGAS PRODUCTION



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(57) Abstract: A method is described for conversion of natural gas or other fossil fuels to higher hydrocarbons, comprising the following steps: a) reaction of natural gas with steam and oxygenic gas in at least one reforming zone in order to produce a synthesis gas consisting primarily of H<sub>2</sub> and CO, in addition to some CO<sub>2</sub>; b) passing said synthesis gas to a Fischer-Tropsch reactor in order to produce a crude synthesis stream consisting of lower hydrocarbons, water and non-converted synthesis gas; c) separation of said crude synthesis stream in a recovery zone, into a crude product stream mainly containing heavier hydrocarbons, a water stream and a tail gas stream mainly containing the remaining constituents; which is characterised in that the method also

comprises the following steps; d) steam reformation of at least part of the tail gas in a separate steam reformer; e) introduction of the reformed tail gas into the gas stream before this is led into the Fischer-Tropsch reactor.

## OPTIMUM INTEGRATION OF FISCHER-TROPSCH SYNTHESIS AND SYNGAS PRODUCTION

The present invention regards a system for chemical conversion of natural gas or  
5 another suitable fossil fuel to synthetic hydrocarbons (syncrude). In particular, the  
present invention regards a system for optimising the production of synthetic  
hydrocarbons.

Known processes for conversion of natural gas or other fossil fuels to synthetic  
10 hydrocarbons comprise two steps. First, the natural gas or other fossil fuel is converted  
to synthesis gas, i.e. a mixture consisting predominantly of hydrogen and carbon  
monoxide, as well as some CO<sub>2</sub>, which in a second step is converted to synthetic  
hydrocarbons through the so-called Fischer-Tropsch (FT) synthesis. The synthetic  
hydrocarbon product normally consists of higher hydrocarbons, i.e. pentane and higher  
15 compounds (C<sub>5+</sub>). The process may also include an additional step in which the  
synthetic hydrocarbon crude product is upgraded to final products.

Synthesis gas for production of synthetic hydrocarbons is normally produced by steam  
reforming or partial combustion, or a combination of these two reactions. The water gas  
20 shift reaction also plays an important part in the production of synthesis gas. These  
reactions may be written as follows:

- 1) steam reforming      CH<sub>4</sub> + H<sub>2</sub>O = CO + 3H<sub>2</sub>      ΔH = 206 kJ/mole
- 2) partial combustion    CH<sub>4</sub> + ½ O<sub>2</sub> = CO + 2H<sub>2</sub>O      ΔH = -519 kJ/mole
- 25 3) water gas shift    CO + H<sub>2</sub>O = CO<sub>2</sub> + H<sub>2</sub>      ΔH = -41 kJ/mole

The Fischer-Tropsch synthesis for producing synthetic hydrocarbons may be written as  
follows:



where [-CH<sub>2</sub>-] is the basic building block for the hydrocarbon molecules. The FT synthesis is highly exothermic, which leads to heat transfer being a significant factor in the design of an FT reactor.

- 5 An important parameter for determining the theoretical maximum yield of synthetic hydrocarbons is the stoichiometric number SN, defined as:

5)  $SN = (H_2 - CO_2) / (CO + CO_2)$

- Theoretically, the yield of synthetic hydrocarbons is at its highest when SN = 2.0 and  
10 CO does not react further to form CO<sub>2</sub> via the water gas shift reaction (equation 3). In this case, the H<sub>2</sub>/CO ratio will be equal to SN, i.e. 2.0, which theoretically gives the highest yield of synthetic hydrocarbons in accordance with equation 4. In practice however, the production of synthesis gas will always involve the water gas shift reaction to a certain degree, so that the CO yield, and thus also the synthetic  
15 hydrocarbon yield, becomes somewhat lower.

- Further, the maximum yield of synthetic hydrocarbons is in reality achieved at a somewhat lower H<sub>2</sub>/CO ratio, typically around 1.6 – 1.8. At an H<sub>2</sub>/CO ratio of 2.0 or more, the synthetic hydrocarbon yield will be reduced due to the formation of more  
20 methane and other lower hydrocarbons (C<sub>4</sub>), which are normally undesirable products.

- The preferred technology for producing synthetic hydrocarbons from synthesis gas is non-catalytic partial oxidation (POX) or autothermal reforming (ATR), in which partial combustion is combined with adiabatic catalytic steam reforming (equation 1) in the  
25 same reactor unit.

- Another technology is combined reforming with a tubular catalytic steam reformer followed by an ATR.  
30 A desired H<sub>2</sub>/CO ratio is achieved by running the synthesis gas reactor with a combination of a low steam/carbon ratio (S/C) and a high temperature, in addition to recirculating part of the CO<sub>2</sub>-rich tail gas from the FT synthesis to the synthesis gas

reactor in order to limit the water gas shift activity (equation 3). In this manner, the H<sub>2</sub>/CO ratio will approach the achieved value of SN.

The drawback of the known techniques for producing synthetic hydrocarbons is low  
5 carbon efficiency in comparison with the theoretical achievement. The carbon efficiency is defined as the relationship between the total amount of carbon in the produced crude product of synthetic hydrocarbons and the total amount of carbon in the natural gas feed. As such, the carbon efficiency is a measure of how much of the carbon in the feed that actually ends up in the final product, and how much ends up as CO<sub>2</sub>. A  
10 plant with low carbon efficiency gives a low product yield, a large CO<sub>2</sub> emission and thus an environmental problem.

As mentioned, catalytic autothermal reforming (ATR) and non-catalytic partial oxidation (POX) are the preferred technologies for production of synthesis gas for the  
15 FT synthesis. By using natural gas as a feed, these technologies produce a synthesis gas with an SN value typically in the range 1.6 to 1.8, which gives the highest yield of synthetic hydrocarbons locally in the FT reactor. However the SN value is lower than 2.0, which for the plant as a whole implies a lower carbon efficiency than that which may theoretically be achieved, due to a hydrogen deficiency.

20 Combined reforming, which normally takes place in a tubular catalytic steam reformer followed by a secondary reformer with an oxygen feed, is capable of producing synthesis gas with an SN value of 2.0, which should theoretically give the highest carbon efficiency in the plant for production of synthetic hydrocarbons. The real carbon efficiency will however not be higher than that which is achieved by use of POX or  
25 ATR, due to the higher degree of recirculation of tail gas to the synthesis reaction that is required in order to restrict a greater water gas shift activity than in the ATR as a result of the higher S/C ratio, and due to a lower yield of the desired higher synthetic hydrocarbons at this SN value.

It is thus an object of the present invention to provide an improved method for conversion of natural gas or other fossil fuels to higher hydrocarbons, in which the above mentioned drawbacks of the known techniques have been overcome.

- 5 According to the present invention, this is achieved by a method for conversion of natural gas or other fossil fuels to higher hydrocarbons, which comprises the steps of:
- a) reacting natural gas with steam and oxygenic gas in at least one reforming zone in order to produce a synthesis gas that consists primarily of H<sub>2</sub> and CO, in addition to some CO<sub>2</sub>;
  - 10 b) lead said synthesis gas to a Fischer-Tropsch reactor in order to produce a crude synthesis stream consisting of lower hydrocarbons, higher hydrocarbons, water, and unconverted synthesis gas;
  - c) separating said crude synthesis stream in a recovery zone, into a crude product stream that primarily contains higher hydrocarbons, a water stream and a tail gas stream that mainly contains the remaining constituents;
- 15 characterised in that the method also comprises the steps of;
- d) steam reforming at least part of the tail gas in a separate steam reformer;
  - e) introducing the reformed tail gas into the gas stream before this is fed into the Fischer-Tropsch reactor.

20

“Lower hydrocarbons” refers to C<sub>1</sub>-C<sub>4</sub> hydrocarbons. “Higher hydrocarbons” refers to C<sub>5+</sub> hydrocarbons.

25 It is preferable for the steam reforming in step d) to take place at conditions that favour the conversion of CO<sub>2</sub> to CO by reversible water gas shift reaction.

Moreover, it is preferable to also hydrogenate that part of the tail gas that is steam reformed, in order to saturate any unsaturated hydrocarbons prior to step d).

30 In a preferred embodiment, natural gas is fed to the steam reformer in step d) together with the tail gas feed.

In a preferred embodiment, the reformed tail gas is introduced into the gas stream after step a), but before step b).

5 In another preferred embodiment, the reformed tail gas is introduced into the gas stream before step a).

It is also preferred that part of the reformed tail gas be introduced into the gas stream before step a) and part of it be introduced after step a) but before step b).

10 Use of the present method has several advantages over previously known techniques.

By reforming and recirculating the tail gas, it becomes possible to:

- Increase the SN value from typically 1.6 – 1.8 for an ATR to approximately 2.0.
- Maintain or increase the CO yield, so that the H<sub>2</sub>/CO ratio approaches the SN value.
- 15 • Achieve an H<sub>2</sub>/CO ratio of less than 2.0 locally at the inlet to the FT reactor, which give a higher yield of higher hydrocarbons.

The present method results in higher carbon efficiency and higher thermal efficiency.

This gives a desired reduction in the CO<sub>2</sub> emission, which is desirable, both for

20 environmental and economic reasons. The oxygen consumption by the present method is lower than in the case of conventional plants for production of synthesis gas by use of POX or ATR, which entails reduced capital costs and lower power consumption.

It is also possible to achieve operational benefits such as increased stability by the  
25 oxygen fired synthesis gas reactor operating at a somewhat lower output temperature than that which is the case when using previously known technology. The increased methane content (lower conversion of natural gas) caused by this will be reformed in the tail gas reformer.

30 By eliminating the recirculation of tail gas to the main section for synthesis gas, it is also possible to economise with regard to the size of the equipment, and thereby to save costs in this section.

The invention will now be explained in greater detail with reference to the accompanying drawings, in which:

- 5    **Figure 1**    is a simplified flow diagram showing the process for producing synthetic hydrocarbons by the present method;
- Figure 2**    is a more detailed flow diagram showing a first preferred embodiment of the present method; and
- Figure 3**    is a more detailed flow diagram showing a second preferred embodiment  
10                 of the present method.

The simplified flow diagram in figure 1 shows a method for producing synthetic hydrocarbons by using natural gas as the main source of carbon and hydrogen, while figures 2 and 3 represent more detailed flow diagrams showing two preferred versions  
15                 of this method.

The present method of FT synthesis based on natural gas or other fossil fuels may be divided into three main parts; that is a first part for production of synthesis gas, a second part for Fischer-Tropsch synthesis (FT synthesis) and a third part for reforming tail gas  
20                 from the FT synthesis.

#### **Production of synthesis gas**

Natural gas enters the plant primarily through natural gas line 1. The natural gas is first heated to typically about 350 – 400 °C before being passed through a desulphurization  
25                 unit 20. Here sulphur, which is present in the natural gas in the form of various organic compounds, is converted to hydrogen sulphide through contacting it with an appropriate hydrogenation catalyst. The hydrogen sulphide is then reduced to a desirable level by use of a zinc oxide layer.

30                 After desulphurization, water vapour is added to the gas in order to ensure a desired ratio between water vapour and carbon (S/C ratio), typically from about 0.6 to 1.3 for production of synthetic hydrocarbons. The gas/water vapour mixture is preheated and

introduced into a prereformer 3 that converts C<sub>2</sub> and higher hydrocarbons to CH<sub>4</sub>, CO and CO<sub>2</sub>. The operating temperature in the prereformer 3 is typically in the range 430 to 500 °C. The prereformer may be omitted, in particular when using natural gas with a low content of C<sub>2+</sub>.

5

Hydrogen, which is required in the desulphurization unit 20 and in the prereformer 3, is added to the natural gas before it enters the desulphurization unit 20. As indicated in the figures, part of the tail gas containing amongst other things hydrogen, may be recirculated and added to the gas before it enters the desulphurization unit 20. It is also 10 possible to recover hydrogen from said tail gas by e.g. pressure swing adsorption (PSA), or hydrogen may be supplied from another source.

The prereformed gas mixture is then heated further to a temperature of typically 550 - 650 °C, before being sent into an autothermal reformer (ATR) 5 together with oxygen 15 or an oxygenic gas such as e.g. air, which comes in through an oxygen inlet 4, normally from a cryogenic oxygen plant (not shown). The gas that is fed to ATR 5 is converted to synthesis gas in ATR 5 through partial combustion in the upper part of ATR 5 and steam reforming of the gases across a nickel catalyst in the lower section of ATR 5. The formation of synthesis gas in ATR 5 typically takes place at a pressure of about 30 – 40 20 bar, and the outlet temperature of the gas from ATR 5 is typically in the range 950 – 1050 °C.

The hot synthesis gas leaving ATR 5 in synthesis gas line 6 is first cooled in a heat exchanger 22, in which typically water from inlet 21 is converted to high pressure steam 25 in outlet 23. One heat exchanger has been indicated in the figures, however in practice there may be a plurality of heat exchangers connected in series, cooling the synthesis gas to the desired temperature. The last cooling down to typically 40 – 70 °C is achieved by use of cooling water.

30 Condensed water is then separated out from the synthesis gas before this is led to a Fischer-Tropsch synthesis reactor 7.

**Fischer-Tropsch synthesis**

The desired synthetic hydrocarbons are formed in a known manner in a Fischer-Tropsch reactor (FT reactor) 7 in which hydrogen and carbon monoxide are converted to higher hydrocarbons, leaving water as a by-product, according to equation (4) above. The FT

5 reactor 7 is typically run at 20 – 40 bar pressure and a temperature of 180 – 240 °C. As the reaction is exothermic, heat is normally removed from the reactor 7 through generation of water vapour at an intermediate pressure of typically around 5 – 20 bar.

The product streams from the FT reactor 7 typically contain the desired product in the

10 form of C<sub>5+</sub> hydrocarbons, by-products in the form of lower hydrocarbons (C<sub>5</sub>), CO<sub>2</sub> and water, as well as non-reacted synthesis gas, i.e. CO and hydrogen. This product stream is separated in a product recovery unit 24, into a crude product stream containing primarily the desired hydrocarbon product in outlet 25, separated water in outlet 26 and a tail gas stream chiefly comprising the above by-products and non-reacted synthesis

15 gas, in tail gas line 9.

The tail gas in tail gas line 9 is in turn split into three. A first part goes through

recirculation line 10 and is compressed in a compressor 27 for recirculation to the synthesis gas production as indicated below, a second part goes through a reforming

20 line 12 to a tail gas reforming process, while a third part is drawn off through bleed line 11 and, if so required, used as fuel in heat consuming parts of the process.

**Tail gas reforming**

The tail gas in tail gas line 12 is preferably first led to a tail gas hydrogenator 28 in order

25 to saturate any unsaturated hydrocarbons. The operating temperature of the

hydrogenator 28 is typically 220 -250 °C, while the operating pressure is around 20 – 40

bar. This tail gas hydrogenator 28 is not obligatory preferred, however unsaturated

hydrocarbons have a greater tendency towards coking than saturated hydrocarbons

· during the subsequent high temperature treatment.

30

After the tail gas hydrogenator 28, water vapour and possibly an amount of natural gas are added to the tail gas in vapour inlet 13 and gas inlet 14 respectively, before the gas

is preheated and passed into a tail gas reformer 15 in which light hydrocarbons are steam reformed on formation of CO and hydrogen, cf. equation 1) above, while CO<sub>2</sub> present in the tail gas is converted to CO through a reverse water gas shift reaction according to equation 3). The natural gas feed can be taken from the product stream 5 from the prereformer 3 (clean split).

The operating temperature of the tail gas reformer is typically above 800°C, preferably from 850 to 950 °C, while the operating pressure is normally from 10 to 40 bar. If so necessitated by the operating pressure difference between the tail gas reformer and the 10 FT reactor, a compressor may be provided downstream of the tail gas reformer. Energy for these reactions can be provided by combustion of fuel that may consist of a small part of the tail gas from bleed line 11.

Depending on the C<sup>2+</sup> content of the gas that may be added in gas inlet 14, it may 15 become necessary to install a prereformer after the addition of water vapour, upstream of the tail gas reformer. The purpose of such a prereformer, which is of the same type as the prereformer 3, is to convert ethane and higher hydrocarbons in the gas stream to methane, CO and CO<sub>2</sub>, thereby to avoid/reduce coking at high temperatures. If no natural gas is added in inlet 14, or when using natural gas with a methane content of 20 90% or more, there will normally not be a requirement for a prereformer here.

The hot flow of reformed tail gas from the tail gas reformer 15 can then be cooled in a heat exchanger 30 in which water that comes in through inlet 31 is converted to water vapour that exits through vapour outlet 32. One heat exchanger has been indicated in the 25 figures, however in practice there may be a plurality of heat exchangers connected in series, cooling the synthesis gas to the desired temperature. Condensed water is then separated out from the reformed tail gas before this is compressed in compressor 33 and led through tail gas line 16 to synthesis gas line 6 before this enters the FT reactor. It is also possible to introduce the reformed tail gas directly into the gas stream between the 30 prereformer 3 and the autothermal reformer (ATR) 5. In addition it will be possible to split the flow of reformed tail gas and lead one component stream to the FT reactor 7 and one component stream to ATR 5.

- The purpose of leading the reformed tail gas to ATR 5 is to achieve further steam reforming and the formation of CO through the reversible water gas shift reaction, as the temperature of ATR 5 is higher than that of the tail gas reformer, thus attaining a
- 5 higher carbon efficiency for the plant. This effect may be partially countered through combustion of CO and hydrogen to CO<sub>2</sub> and water. The choice of solution here, and any decision regarding how much of the reformed tail gas goes where, will depend on a number of operational parameters.
- 10 The primary purpose of reforming and recirculating tail gas according to the present invention is to steam reform lower hydrocarbons to CO and hydrogen, thereby to increase the stoichiometric number SN towards the desired value of 2.0, which is an important condition for achieving a significantly higher efficiency for the process plant. As the tail gas contains little in the way of light hydrocarbons, steam reforming of this
- 15 stream alone will only give a limited increase in efficiency. Adding natural gas or another source of lower hydrocarbons through gas inlet 14 will therefore give a further increase in carbon efficiency.

- Another advantage of adding natural gas to the tail gas reformer is to reduce the amount
- 20 of feed gas to ATR 5, which gives a lower oxygen consumption than that of a conventional synthesis plant with ATR.

#### **The overall system**

- In total, the present method gives a noticeable and important increase in the carbon
- 25 efficiency, a reduction of the oxygen consumption and improved overall economy for the plant.

- By reforming and recirculating a significant portion of the tail gas to the FT reactor 7 and/or ATR 5, the equipment in the feed section to the ATR unit can be smaller than
- 30 that which would be the case if the tail gas were to be recirculated to the hydrogenation unit 28, as is common today.

The tail gas from the product recovery section 24 is, as mentioned above, split into three parts. It has proven advantageous to recirculate 0 – 20 %, for example around 10 %, to the hydrogenation unit 28; use 0 – 40 %, for example around 30% as fuel in the tail gas reformer; and use 40 – 80 %, for example around 60%, as feed to the tail gas reforming  
5 part of the process.

**Example**

Five different plants / modes of operation of the plant were simulated in order to show the advantages of the present invention compared with previously known technology  
10 traditionally used in plants for synthesis of synthetic hydrocarbons. In all the examples, the production was set at 20 000 BPD or 101 tons/hour.

The examples were as follows:

**Ex. A** Production of synthetic hydrocarbons by conventional autothermal reforming (ATR).

15

**Ex. B** Production of synthetic hydrocarbons by conventional combined reforming.

20

**Ex. C** Production of synthetic hydrocarbons by ATR and F-T tail gas reformer. No addition of natural gas to the tail gas reformer. The product from the tail gas reformer was fed to the F-T reactor.

25

**Ex. D** Production of synthetic hydrocarbons by ATR and F-T tail gas reformer. 10% of the natural gas feed to the process is added directly to the tail gas reformer. The product from the tail gas reformer was fed to the F-T reactor. The portion of the tail gas that is drawn off from the plant is used as fuel gas in the tail gas reformer.

30

**Ex. E** Production of synthetic hydrocarbons by ATR and F-T tail gas reformer. 20% of the natural gas feed to the process is added directly to the tail gas reformer. The product from the tail gas reformer was fed to ATR. 3 % of the total natural gas feed is used as fuel in the tail gas reformer together with the portion of the tail gas that is drawn off from the plant.

The crude product was natural gas with the following composition:

CO <sub>2</sub>	1,84 %
N <sub>2</sub>	0,36 %
CH <sub>4</sub>	80,89 %
C <sub>2</sub> H <sub>6</sub>	9,38 %
C <sub>3</sub> H <sub>8</sub>	4,40 %
C <sub>4</sub> H <sub>10</sub>	2,18 %
C <sub>5</sub> H <sub>12</sub>	0,62 %
C <sub>6</sub> H <sub>14</sub>	0,22 %
C <sub>8</sub> H <sub>18</sub>	0,11 %

These simulations gave the following results as to the most important key data:

	Ex. A Compar. ex.	Ex. B Compar. ex.	Ex. C	Ex. D	Ex. E
Natural gas feed, kmol/h	7 767	7 790	7 150	7 062	7 070
S/C, synthesis gas line	0.6	1.8	0.6	0.6	0.6
Oxygen consumption, ton/day	4 590	3 289	3 801	3 399	3 290
Fischer-Tropsch tail gas used as fuel gas, % of total tail gas	40	25	30	30	30
Fischer-Tropsch tail gas added to ATR, % of total tail gas	60	75	9	9	9
Fischer-Tropsch tail gas added to tail gas reformer, % of total tail gas	-	-	61	61	61
S/C <sup>3</sup> tail gas reformer	-	-	5.3	1.0	0.6
CO <sub>2</sub> /C <sup>3</sup> tail gas reformer	-	-	5.3	1.0	0.6
Outlet temperature tail gas reformer, °C	-	-	900	900	900
Carbon efficiency, % <sup>1</sup>	71.0	70.9	77.1	78.0	77.9
Thermal efficiency, % <sup>2</sup>	59.4	59.2	64.6	65.3	65.3
CO <sub>2</sub> emission, ton/h	127.11	128.39	92.50	87.46	88.00

- 1 Carbon efficiency = amount of carbon in the synthetic crude product/total amount of carbon in the natural gas feed
- 5 2 Thermal efficiency = lower thermal value (i.e. the thermal value obtained by complete combustion) in the synthetic crude product/lower thermal value in total natural gas feed
- 3 Organic carbon
- 10 The above table clearly shows the advantages of using of the present method (ex. C, D and E) in preference to the previously known methods (ex. A and B).

For the same quantity of product, the present method reduces the consumption of natural gas by around 8 – 10 %, which in turn is directly reflected by the carbon

efficiency and the thermal efficiency, which for the present method are significantly higher than when using the previously known methods.

- Another significant effect, which is clearly associated with the above results, is that of  
5 the considerable reduction in CO<sub>2</sub> emissions for the same produced quantity of synthetic hydrocarbons. As can be seen from the above table, the CO<sub>2</sub> emissions by use of the present method are around 40% lower than those caused by use of conventional methods.
- 10 The oxygen consumption in example B, which is a method according to prior art, was the lowest among the simulated examples. Although low oxygen consumption is positive, the results for the critical parameters, i.e. carbon efficiency and thermal efficiency, are significantly poorer than in the case of the present invention, i.e. examples C, D and E.
- 15 The above invention has been described as using natural gas as the source of carbon. The process may however be used for all types of gas that contain large amounts of lower hydrocarbons, as well as for other fossil fuels and possibly combinations of various carbon sources.

P a t e n t c l a i m s

1.

A method for conversion of natural gas or other fossil fuels to higher hydrocarbons,  
5 comprising the following steps:

- a) reaction of natural gas with steam and oxygenic gas in at least one reforming zone in order to produce a synthesis gas consisting primarily of H<sub>2</sub> and CO, in addition to some CO<sub>2</sub>;
  - b) passing said synthesis gas to a Fischer-Tropsch reactor in order to produce a  
10 crude synthesis stream consisting of lower hydrocarbons, water and non-converted synthesis gas;
  - c) separation of said crude synthesis stream in a recovery zone, into a crude product stream mainly containing higher hydrocarbons, a water stream and a tail gas stream mainly containing the remaining constituents;
- 15 c h a r a c t e r i s e d i n that the method also comprises the following steps;
- d) steam reformation of at least part of the tail gas in a separate steam reformer;
  - e) introduction of the reformed tail gas into the gas stream before this is led into the Fischer-Tropsch reactor.

20

2.

Method according to Claim 1, c h a r a c t e r i s e d i n that the temperature during the steam reforming in step d) is above 800 °C, preferably from 850 to 950 °C.

25

3.

Method according to Claim 1 or 2, c h a r a c t e r i s e d i n that the portion of the tail gas that is steam reformed is also hydrogenated in order to saturate any unsaturated hydrocarbons prior to step d).

30

4.

Method according to one or more of the preceding claims,  
characterised in that natural gas is added to the steam  
reformer in step d) together with the tail gas feed.

5

5.

Method according to one or more of the preceding claims,  
characterised in that the reformed tail gas is introduced  
into the gas stream after step a), but before step b).

10

6.

Method according to one or more of Claims 1 to 4,  
characterised in that the reformed tail gas is introduced  
into the gas stream before step a).

15

7.

Method according to one or more of Claims 1 to 4,  
characterised in that a portion of the reformed tail gas is  
introduced into the gas stream before step a), and a portion is introduced after step a)  
but before step b).

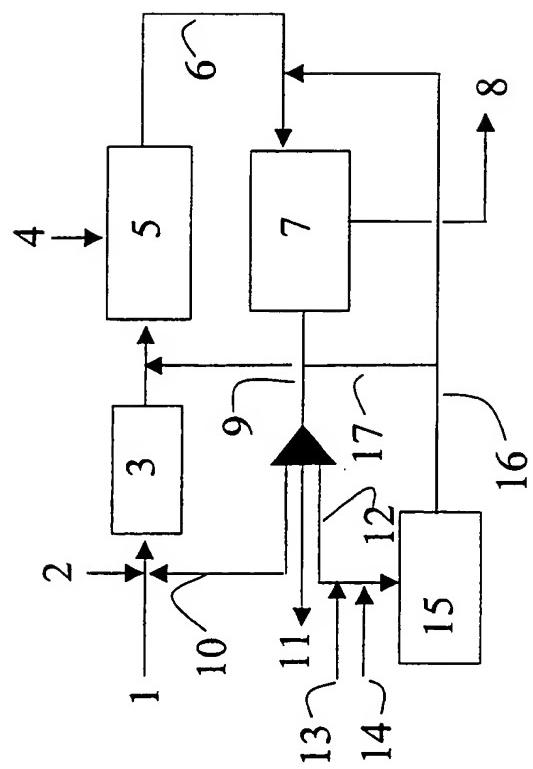


Fig. 1

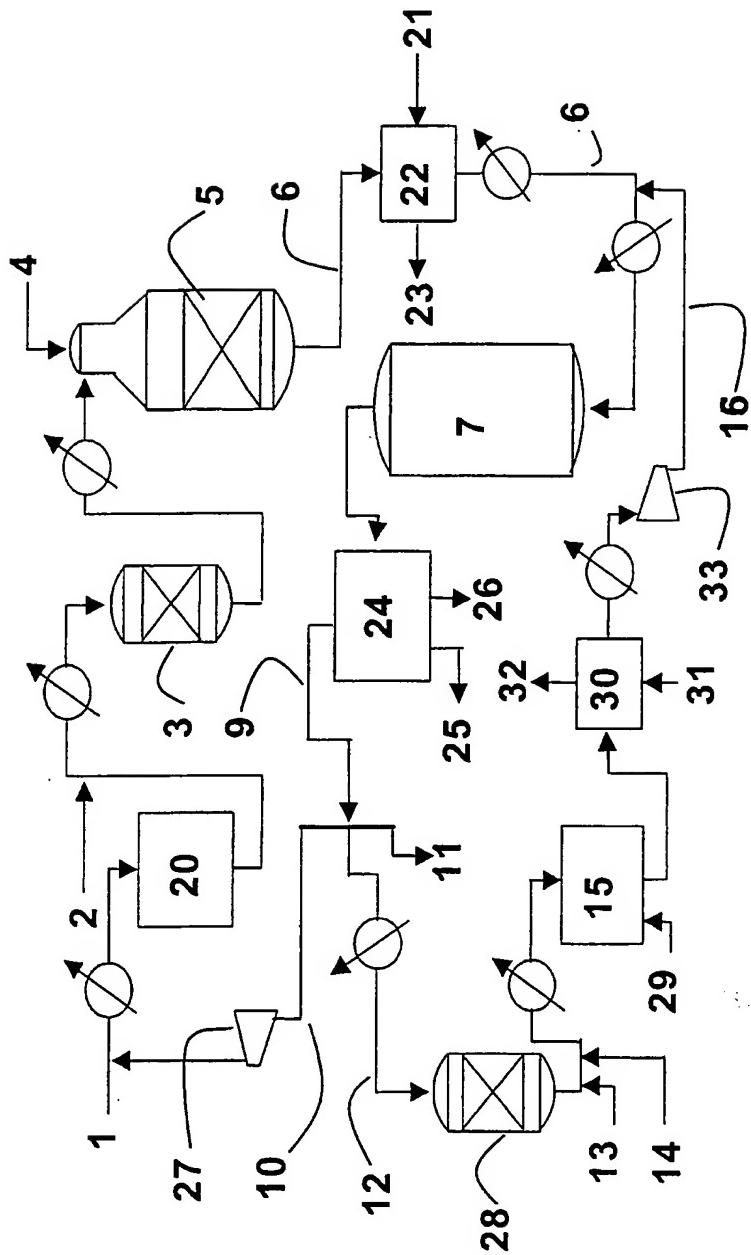


FIG. 2

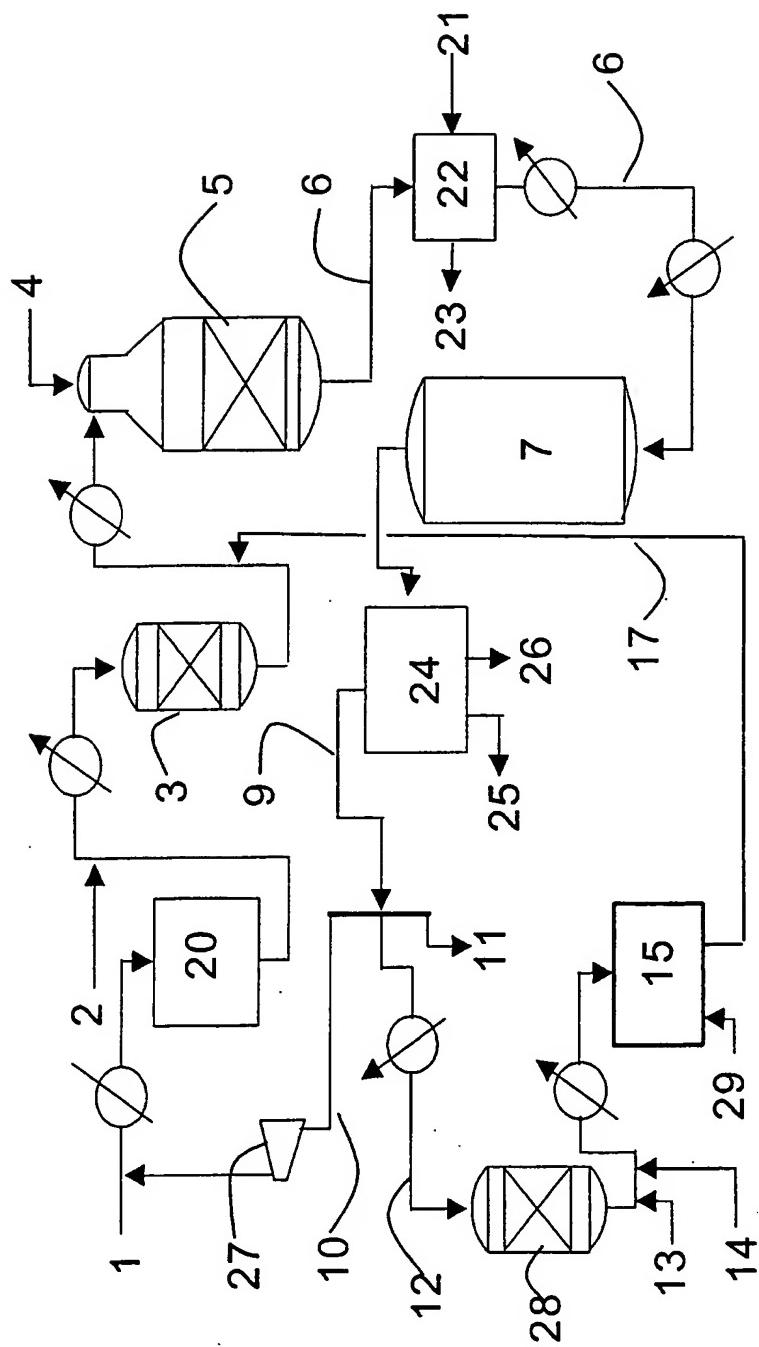


FIG. 3

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/NO 00/00404

## A. CLASSIFICATION OF SUBJECT MATTER

IPC7: C07C 1/04, C10G 2/00, C01B 3/36

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: C07C, C01B, C10G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0516441 A1 (THE BRITISH PETROLEUM COMPANY P.L.C.), 2 December 1992 (02.12.92), abstract; page 2, line 33 - line 45; claims 1-2 --	1-7
X	GB 2223029 A (SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.), 28 March 1990 (28.03.90), abstract; claims 1-3 -- -----	1-7

 Further documents are listed in the continuation of Box C. See patent family annex.

## \* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
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- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search  
  
20 March 2001Date of mailing of the international search report  
10.04.2001Name and mailing address of the ISA/  
European Patent Office

Authorized officer

Facsimile No.

DAGMAR JÄRVMAN/EÖ  
Telephone No.

S/ 16789

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

25/02/01

International application No.
PCT/NO 00/00404

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
EP	0516441	A1	02/12/92	AT AU AU CA CN CN DE FI JP MX NO NZ ZA	165073 T 663082 B 1717292 A 2068115 A 1048009 B 1067067 A 69225089 D,T 922352 A 6184559 A 9202577 A 922120 A 242569 A 9203385 A	15/05/98 28/09/95 03/12/92 01/12/92 05/01/00 16/12/92 06/08/98 01/12/92 05/07/94 01/01/93 01/12/92 26/07/94 27/01/93
GB	2223029	A	28/03/90	GB	8815622 D	00/00/00